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IN THE U.S. PATENT AND TRADEMARK OFFICE #3

Applicant: Koji Minami, et al.

Appl. No.: 09/481,391 Group: 2614

Filed: January 12, 2000 Examiner: YENKE, B.

For: DISPLAY DEVICE

PETITION UNDER 37 C.F.R. §1.182

Honorable Commissioner for Patents
Washington, DC 20231

April 9, 2001

Sir:

The Honorable Commissioner is respectfully requested to disregard the English language specification and drawings filed on January 12, 2000 in connection with the above-identified application and consider the Japanese specification filed January 12, 2000 (a copy of Japanese-language application no. 079518/1999) as the specification and drawings for the present application. The Honorable Commissioner is also respectfully requested to grant the present application a U.S. filing date of January 12, 2000, based on the Japanese language application filed on January 12, 2000.

Applicants respectfully request that the copy of Japanese-language application no. 079518/1999 filed on January 12, 2000 be considered the specification and drawings for the present application for the following reasons:

1) Applicants U.S. representative was supplied a copy of an English-language U.S. specification and drawings for the present application, a copy of Japanese-language priority application 079518/1999 and a copy of an English-language specification and drawings for co-pending application Serial number 09/369,310.

2) In preparing the application for filing prior to January 12, 2000, applicants U.S. representative inadvertently mislabeled the copy of the English-language specification and drawings for co-pending application 09/369,310 as the English-language specification and drawings for the present application.

3) On January 12, 2000, applicants U.S. representative incorrectly filed the copy of English-language specification and drawings for co-pending application 09/369,310 as the English-language specification and drawings for the present application.

4) On January 12, 2000, applicants U.S. representative also filed a copy of Japanese-language application no. 079518/1999. This specification filed on January 12, 2000 clearly discloses the intended subject matter of the present application and contains all necessary elements (including claims) to be accorded a filing date.

5) On November 22, 2000, the Examiner of the present application issued an Office Action rejecting the claims of the present application under 35 U.S.C. §102(e) as being anticipated by co-

pending application no. 09/369,310, rejected claims 1-10 provisionally under 35 U.S.C. §101 as claiming the same invention as that of claims 1-10 of co-pending application no. 09/369,310 and questioned the issue of priority under 35 U.S.C. §102(g) and possibly 35 U.S.C. §102(f) in view of claims 1-10 of co-pending application no. 09/369,310. This was the first time the above error came to the attention of anyone substantively involved in the prosecution of the present application.

6) Applicants U.S. representative reported the Office Action of November 22, 2000 in a letter to the Assignee of the present application on December 18, 2000.

7) Based on communication from the Assignee on December 28, 2000, applicants U.S. representative discovered that the incorrect English-language specification and drawings were filed on January 12, 2000. In particular, the English-language specification and drawings for co-pending application 09/369,310 were filed instead of the correct English-language specification and drawings.

8) Applicants have enclosed herewith a complete copy of Japanese application no. 079518/1999, as filed on January 12, 2000, as well as an English translation of Japanese application no. 079518/1999. Applicants have also included a sworn translation verifying that the attached English language translation is an

accurate translation of Japanese application no. 079518/1999. Applicants also enclosed a new Declaration and Assignment as well as a new Information Disclosure Statement to replace the one originally filed on January 12, 2000.

DISCUSSION

Applicants respectfully request the Honorable Commissioner to disregard all other papers filed on January 12, 2000 and consider the copy of Japanese-language application no. 079518/1999 to be the specification and drawings for the present application and accord applicants a U.S. filing date of January 12, 2000 based on the Japanese-language application.

The Japanese specification complies with the provisions of 37 C.F.R. 1.51. The specification in Japanese includes claims as required by 37 C.F.R. 1.51(b)(1) and a declaration of the inventors was also supplied.

The Patent and Trademark Office is respectfully requested to approve the filing of the Japanese language application as the specification and provide applicant's an opportunity to file the attached translation, statement of translation accuracy and fee of $130.00 as set forth in 37 C.F.R. 1.52(d).

Favorable and early consideration of this Petition is earnestly solicited.

If the Examiner has any questions concerning this application, the Examiner is requested to contact John A. Castellano, Registration No. 35,094 at (703) 205-8000 in the Washington, D.C. area.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any fees required under 37 C.F.R. §§1.16 or 1.17.

Respectfully submitted,

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JAC:cb
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[Name of Document]: Specification

[Title of the Invention]: Display Device

[Claims]

1. In a display device having a light source and four or more kinds of color filters including a color filter Cw showing almost flat transmission spectral characteristics in the visible range, the display device being designed to display an image by passing light emitted from said light source through the color filters,

the improvement wherein information corresponding lower-order m bits of a brightness signal of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed through said color filter Cw, and wherein information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw.

2. In a display device having a light source and four or more kinds of color filters including a color filter Cw that transmits white light, the display device being designed to display an image by passing light emitted from said light source through the color filters,

the improvement wherein information corresponding lower-order m bits of a brightness signal of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed

through said color filter Cw, and wherein information corresponding to upper-order *n* bits is displayed by light passed through the color filters other than said color filter Cw.

3. In the display device set forth in claim 1 or 2, the further improvement wherein a display is provided using light transmitted through the color filter Cw only when a signal corresponding to brightness information of said color image signal is less than a given gray level.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to a display device and, more particularly, to a display device using color filters to reproduce colors.

[0002]

[Prior Art Techniques]

In recent years, numerous display devices have been available in which color filters are used to decompose light from a light source into N kinds of colors that are projected onto a screen for reproducing a color image, where N is a positive integer. Normally, N = 3, and light is decomposed into red (R), green (G), and blue (B) colors which are projected to reproduce a color image.

[0003]

Fig. 5 is a diagram showing a first conventional example

of a display device.

[0004]

Shown in Fig. 5 are a light source 101, a color wheel 102, a light valve 103, a screen 104, and a driver portion 105. The display device shown in Fig. 5 is assumed to project light decomposed into R, G, and B colors, thus reproducing color images.

[0005]

The operation of the first conventional display device is described below by referring to Fig. 5. Seven-bit color image data having a frame rate of 60 Hz and a synchronizing signal are applied to the driver portion 105. The driver portion 105 creates control signals for the color wheel 102 and for the light valve 103 from the entered color image data and the synchronizing signal. The control signals are fed to the color wheel 102 and to the light valve 103.

The light valve 103 is a device for turning ON or OFF light for each individual pixel. A digital micromirror device (hereinafter abbreviated DMD), a liquid crystal, or the like is used as the light valve 103. Where the DMD is used as the light valve 103, the direction in which light is reflected is controlled for each individual pixel, thus turning ON or OFF the light. Where the light is reflected toward the screen, the device is turned ON. Where the light is reflected toward the outside the screen, the device is turned OFF. This will

hereinafter be referred to as "control of the reflection". In the case of a liquid crystal, two types are conceivable. One type controls reflection in the same way as the aforementioned DMD. Another type switches ON and OFF passage of light for each individual pixel. Where the light is transmitted, the device is turned ON. Where the light is not transmitted, the device is turned OFF. It is now assumed that the transmitted light is brought to a focus on the screen.

[0006]

An ultrahigh-pressure mercury lamp is used as the light source 101, for example. Light emitted from this lamp is made to hit a part of the color wheel 102.

[0007]

The color wheel 102 is divided into three segments, for example. These segments are color filters Cr, Cg, and Cb that transmit R, G, and B, respectively. The color wheel 102 makes one revolution in 1/60 msec, i.e., about 16.667 msec. This rotation is synchronized to the frame rate of the displayed image.

[0008]

Where light from the light source 101 shines on the color filter segment Cr on the color wheel 102, the light valve 103 is controlled by color image data about R. An R image is projected onto the screen 104. With respect to other colors, the light from the light source 101 is similarly projected onto the screen

104 via the color filters on the color wheel 102 and via the light valve 103, and images are displayed.

[0009]

The times for which the light from the light source 101 is made to shine on the segments of the color wheel 102 during one revolution of the color wheel 102 are next described. The light source 101 illuminates parts of the color wheel 102. At this time, the light spot has some diameter. Where this light spot is at the boundary between two adjacent color filters, two colors across the boundary will be mixed up. This cannot be used for image display. Therefore, it is necessary to turn OFF the light valve. For the sake of illustration, it is assumed that the light valve must be kept OFF within an angular range of 15° on the color wheel 102. Of course, this angular range may differ, depending on the size of the light spot and on the sizes of the color filters.

[0010]

Since the boundaries between the color filters on the color wheel 102 are three, it is necessary to turn OFF the light valve 103 for a time corresponding to an angular range of $15 \times 3 = 45°$ during one revolution of the color wheel 102. This time is referred to as the ineffective time. The other time is referred to as the effective time. Since the color wheel 102 makes one revolution in about 16.667 msec, the ineffective time is $45°/360° \times 16.667 \cong$ approximately 2.083 msec.

Of the effective time, the time for which the light shines on the color filter Cr is equal to the effective time divided by 3, i.e., about 4.862 msec. Similarly, the time for which the light shines on the color filters Cg and Cb is about 4.862 msec.

[0011]

A method of reproducing gray levels regarding R is now described.

[0012]

When the light shines on the color filter Cr during the effective time of the color wheel 102, the light valve 103 is controlled according to an R image signal. Where the first gray level of R image signal is displayed, the light valve 103 is turned ON for about 0.038 msec within the time for which the light shines on the color filter Cr during one revolution of the color wheel 102. The light valve 103 is kept OFF during the remaining time of about 4.824 msec. Where the second gray level is displayed, the light valve 103 is turned ON for twice of the ON time for the first gray level, i.e., 0.076 msec. The light valve is kept OFF during the remaining time of 4.786 msec. Where the third, fourth, …, and 127th gray levels are displayed, the light valve is turned ON for 3 times, 4 times, …, and 127 times, respectively, the ON time for the first gray level. The light valve is kept OFF during the remaining times. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

[0013]

The human eye does not respond to flickers higher than 60 Hz, which is generally known as the critical fusion frequency. As the ON time increases within the 16.667 msec, the human eye feels brighter. As the ON time shortens, the eye feels darker. The human eye perceives 128 ON/OFF time combinations as 128 gray levels.

[0014]

Light is projected onto the screen such that the light valve is turned ON or OFF for each pixel, and an R image that visually has gray levels is reproduced.

[0015]

With respect to each of G and B, 128 gray levels are reproduced in exactly the same way.

[0016]

Each image of R, G, and B is projected in turn onto the screen for one third of 1 frame time of about 16.667 msec, i.e., about 5.556 msec. As mentioned above, the human eye does not respond to flickers higher than the critical fusion frequency of 60 Hz and so he or she feels as if three colors were displayed simultaneously. Consequently, a color image is visually reproduced.

[0017]

In the first conventional example described thus far, gray levels corresponding to 7 bits, i.e., 128 gray levels are represented. The light valve 103 is switched ON and OFF at

intervals of about 0.038 msec, i.e., the time (about 4.862 msec) for which light is made to shine on the color filter Cr divided by 127. Where it is attempted to display 256 gray levels corresponding to 8 bits in this first conventional example, it is necessary to switch ON and OFF the light valve 103 at intervals within the time for which light is made to shine on the color filter Cr divided by 255, i.e., about 0.019 msec. If it is assumed that the minimum switching time in which the light valve 103 turns ON and OFF light is about 0.030 msec, then it is impossible to achieve.

[0018]

A second conventional example capable of displaying 1024 gray levels if the minimum switching time in which the light valve 103 turns ON and OFF light is about 0.030 msec is now given. The second conventional example is a technique disclosed, for example, in Japanese Unexamined Patent Publication No. 149350/1997.

[0019]

Fig. 6 is a diagram showing the second conventional example. Those portions which have the same functions as their counterparts in Fig. 5 are indicated by the same numerals in both figures and thus will not be described below.

[0020]

In this second conventional example, a color wheel 202 is divided into 6 segments to add color filters Crd, Cgd, and

Cbd of lower transmissivity compared with the first conventional example. These are used to add gray levels corresponding to the 3 bits.

[0021]

The second conventional example is described below by referring to Fig. 6. In the figure,

[0022]

a driver portion 205 receives 10-bit color image data having a frame rate of 60 Hz and a synchronizing signal. The driver portion 205 creates control signals for a color wheel 202 and for a light valve 103 from the input color image data and sends these control signals to the wheel 202 and to the light valve 103.

[0023]

Of the 6 segments on the color wheel 202, the color filters Cr and Crd transmit R. The color filters Cg and Cgd transmit G. The color filters Cb and Cbd transmit B. The transmissivity of the filter Crd is one eighth of that of the filter Cr. The transmissivity of the color filter Cgd is one eighth of that of the filter Cg. The transmissivity of the color filter Cbd is one eighth of that of the filter Cb. The color wheel 202 makes one revolution in 1/60 msec ≅ 16.667 msec. This rotation is synchronized to the frame rate of the displayed image.

[0024]

In the second conventional example, there are 6 kinds of

color filters and so there exist 6 boundaries. Therefore, the ineffective time is about $15° \times 6 / 360° \times 16.667$ msec $\cong 4.167$ msec. The effective time is about 16.667 msec − 4.167 msec = 12.500 msec.

[0025]

The time for which the light from the light source 101 is made to shine on the color filter Cr of the color wheel 202 during one revolution of the color wheel 202 is about 12.500 msec / 3 × 127 / (127 + 7) = 3.949 msec. Similarly, the time for which light is made to hit the color filters Cg and Cb is also about 3.949 msec. The area of the color filter Crd is so determined that the time for which the color filter Crd is illuminated is about 12.500 msec/ 3 × 7 / (127 + 7) = 0.218 msec. The time for which the color filters Cgd and Cbd is illuminated is also about 0.218 msec.

[0026]

A method of reproducing gray levels about R is described next.

[0027]

The time for which the color filter Cr on the color wheel 202 is illuminated is controlled according to R color image data. Where the first gray level of the R image signal is displayed, the light valve 103 is turned ON for about 0.031 msec of the time for which the color filter Cr is illuminated during one revolution of the color wheel 202. The valve is kept OFF during

the remaining time. Where the second gray level is displayed, the light valve 103 is maintained ON during twice of the ON time for the first gray level, i.e., about 0.062 msec. The valve is kept OFF during the remaining time. Where the third, the fourth, …, and the 127th gray levels are displayed, the light valve is turned ON for 3 times, 4 times, …, 127 times, respectively, the ON time for the first gray level. The light valve is kept OFF during the remaining times. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

[0028]

A method of increasing the number of gray levels for R to 1024 using the color filter Crd is next described. Where the first gray level by the color filter Crd is displayed, the light valve 103 is kept ON for about 0.031 msec within the time for which the color filter Crd is illuminated during one revolution of the color wheel 202. The valve is kept OFF during the remaining time. Where the second gray level is displayed, the valve is kept ON for twice of the ON time for the first gray level, i.e., 0.062 msec. The valve is kept OFF during the remaining time. Where the third, fourth, …, and 7th gray levels are displayed, the light valve is kept ON for 3 times, 4 times, …, 7 times, respectively, the ON time for the first gray level. The valve is kept OFF during the remaining time.

Thus, 8 gray levels including a fully OFF state can be reproduced.

[0029]

The transmissivity of the color filter Crd is one eighth of that of the color filter Cr. The brightness of the first gray level displayed using only the color filter Crd is one eighth of that of the first gray level displayed using only the color filter Cr. Therefore, 1024 gray levels can be reproduced by displaying the upper-order 7 bits of the color image data quantized with 10 bits by the use of the color filters Cr, Cg, and Cb and displaying the lower-order 3 bits by the use of the color filters Crd, Cgd, and Cbd.

[0030]

With respect to G and B, the upper-order 7 bits are expressed using the color filters Cg and Cb. The lower-order 3 bits are represented using the color filters Cgd and Cbd. In this manner, 1024 gray levels can be reproduced.

[0031]

Subsequently, R, G, and B are projected onto the screen 104 in the same way as in conventional example 1. A color image is created by the human visual sensation characteristics.

[0032]

Where 1024 gray levels are accomplished using the structure described above, the brightness becomes lower than in the first conventional example, thus presenting a problem. The main reason is that the color wheel 202 is divided into 6 segments unlike the first conventional example. Therefore,

there are 6 boundaries between the color filters. The ineffective time is doubled. Consequently, the brightness decreases by about 14%. In addition, the presence of the color filters having a brightness of one eighth lowers the brightness.

[0033]

[Problems to be Solved by the Invention]

In the first conventional display device, the number of gray levels is limited by the minimum switching time in which the light valve 103 is turned ON and OFF. Hence, only 128 gray levels can be reproduced. The second conventional example can increase the number of gray levels to 1024 but a decrease in the brightness occurs.

[0034]

This invention has been made to solve the foregoing problems. It is an object of the present invention to provide a display device which can reproduce gray levels more than the number of gray levels limited by the minimum switching time in which a light valve is turned ON and OFF, the display device suffering from almost no brightness decrease.

[0035]

[Means for Solving the Problems]

A display device in accordance with this invention has a light source and four or more kinds of color filters including a color filter Cw showing almost flat transmission spectral characteristics in the visible range, the display device being

designed to display an image by passing light emitted from said light source through the color filters. The display device is characterized in that information corresponding lower-order m bits of a brightness signal of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed through the color filter Cw, and in that information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw.

[0036]

The invention also provides a display device having a light source and four or more kinds of color filters including a color filter Cw that transmits white light, the display device being designed to display an image by passing light emitted from said light source through the color filters. The display device is characterized in that information corresponding lower-order m bits of a brightness signal of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed through said color filter Cw, and in that information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw.

[0037]

In another feature, a display is provided using light transmitted through the color filter Cw only when a signal

corresponding to brightness information of said color image signal is less than a given gray level.

[0038]

[Embodiments of the Invention]

This invention is hereinafter described in detail with reference to the drawings showing its embodiments.

[0039]

Embodiment 1

Fig. 1 is a block diagram showing one example of the structure of a display device in accordance with one embodiment of this invention. Shown in Fig. 1 are a light source 101, a color wheel 2, a light valve 103, a screen 104, a signal converter portion 6, and a driver portion 5.

[0040]

The color wheel 2 is divided into 4 segments including color filters Cr, Cg, and Cb that transmit R, G, and B, respectively. The color wheel 2 further includes a color filter Cw that transmits white light. This filter Cw shows almost flat spectral characteristics, as opposed to the filters Cr, Cg, and Cb in the visible range. Let the color filters Cr, Cg, Cb, and Cw have transmissivities of $fr(\lambda)$, $fg(\lambda)$, $fb(\lambda)$, and $fw(\lambda)$, respectively. $fw(\lambda)$ is so set as to satisfy Equation (1).

[0041]

[Equation 1]

$$\int_{380}^{780} fw(\lambda) \cdot V(\lambda)\, d\lambda = \frac{1}{8} \cdot \int_{380}^{780} \{fr(\lambda) + fg(\lambda) + fb(\lambda)\} \cdot V(\lambda)\, d\lambda \qquad (1)$$

[0042]

where λ is the wavelength of light and V(λ) is the relative spectral sensitivity characteristic of the human eye.

It can be seen that the color filter Cw is lower in transmissivity than the color filters Cr, Cg, and Cb, because the right side of equation (1) is multiplied by a coefficient 1/8. In other words, the brightness of the first gray level displayed using only the color filter Cw is one eighth of the brightness achieved when the three color filters Cr, Cg, and Cb are simultaneously set to the first gray level.

[0043]

The display device in accordance with the present embodiment constructed in this way decomposes light into 4 colors by the color filters Cr, Cg, Cb, and Cw. The 4 colors of light are projected via the light valve 103 onto the screen 104, thus reproducing a color image.

[0044]

The operation of the display device of Fig. 1 is next described. Color image data of 10 bits having a frame rate of 60 Hz is input to the signal converter portion 6. This converter portion 6 converts the input color image data as follows and sends it to the driver portion 5. The driver portion 5 also receives a synchronizing signal.

[0045]

The manner in which the signal converter portion 6 converts color image data is now described by referring to Fig. 2, which is a detail block diagram of the signal converter portion 6. In Fig. 2, input terminals 7, 8, and 9 receive 10-bit, color image data Rin, Gin, and Bin, respectively, corresponding to the R, G, and B colors. A brightness signal-calculating unit 10 for calculating brightness data Y satisfies equation (2) below, assuming that the lower-order 3 bits of the input color image data Rin, Gin, and Bin are Sr, Sg, and Sb, respectively. The upper-order 3 bits of the brightness data Y is supplied as a converted color image data Wout to an output terminal 17. Delay-compensating portions 11, 12, and 13 delay with respect to the upper-order 7 bits of the signals Rin, Gin, and Bin coming from the input terminals 7, 8, and 9 by an amount equal to the time taken for the brightness signal-calculating unit 10 to calculate the brightness signal. The obtained data are sent as converted color image data Rout, Gout, and Bout to output terminals 14, 15, and 16, respectively.

[0046]

[Equation 2]

$$Y = 0.299Sr + 0.587Sg + 0.144Sb \qquad (2)$$

[0047]

The output terminals 14, 15, 16, and 17 are connected with the driver portion 5, which in turn creates control signals for

the color wheel 2 and light valve 103 from the converted color image data Rout, Gout, Bout, Wout and from the synchronizing signal and sends the control signals to the color wheel 2 and to the light valve 103.

[0048]

The color wheel 2 makes one revolution in 1/60 msec ≅ 16.667 msec. This rotation is synchronized with the frame rate of the displayed image.

[0049]

The color wheel 2 has 4 kinds of color filters that form only four boundaries. Therefore, the ineffective time is about $15° \times 4 / 360° \times 16.667$ msec = 2.778 msec. The effective time is about 16.667 msec − 2.778 msec = 13.889 msec.

[0050]

The area of the color filter Cr is determined in such a way that light from the light source 101 shines on the color filter Cr of the color wheel 2 for 13.889 msec × 127/(3 × 127 + 7) = 4.546 msec during one revolution of the color wheel 2. The time for which the color filters Cg and Cb are illuminated is also 4.546 msec. The area of the color filter Cw is so set that the time for which the color filter Cw is illuminated is 13.889 msec × 7 (3 × 127 + 7) = 0.251 msec.

[0051]

A method of reproducing gray scales about R is next described.

[0052]

The light valve 103 is controlled according to the converted color image data Rout about R produced from the output terminal 14 of the signal converter portion 6 while the color filter Cr is being illuminated with light. Where the first gray level of the converted color image data Rout about R is displayed, the light valve 103 is kept ON during about 0.036 msec within the time for which the color filter Cr is illuminated during one revolution of the color wheel 2. The valve is kept OFF during the remaining time. Where the second gray level is displayed, the valve is kept ON during twice of the time for the first gray level (i.e., 0.072 msec). The valve is kept OFF during the remaining time. Where the third, fourth, …, and 127th gray levels are displayed, the light valve is kept ON for 3 times, 4 times, …, 127 times, respectively, the ON time for the first gray level. The valve is kept OFF during the remaining time. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

[0053]

As mentioned above, the human eye does not respond to flickers of 60 Hz or faster and so he or she feels brighter with increasing the ON time within the period of 16.667 msec and feels darker with decreasing the ON time. The human eye perceives the 128 combinations of ON/OFF times as 128 gray levels.

[0054]

In exactly the same way, 128 gray levels are reproduced

about G and B images.

[0055]

A method of reproducing gray levels equal to or more than 129 gray levels using the color filter Cw of the color wheel 2 is described.

[0056]

The upper-order 7 bits of the color image data Rin, Gin, and Bin quantized with 10 bits are displayed using the 128 gray level-reproducing capability of the aforementioned color filters Cr, Cg, and Cb. On the other hand, the lower-order 3 bits of the color image data Rin, Gin, and Bin that are discarded are displayed as converted color image data Wout quantized with 3 bits (i.e., 8 gray levels) using the color filter Cw.

[0057]

Where the first gray level of Wout is displayed, the light valve 103 is kept ON for 0.036 msec within the time for which the color filter Cw is illuminated during one revolution of the color wheel 2. The valve is kept OFF during the remaining time. Where only the second gray level is displayed, the valve is kept ON during twice of the ON time for the first gray level, i.e., 0.072 msec. The valve is kept OFF during the remaining time. Where the third, fourth, …, and seventh gray levels are displayed, the light valve is kept ON during three times, four times, …, and 7 times, respectively, the time for the first gray level. The valve is kept OFF during the remaining time.

In this way, 8 gray levels including a fully OFF state can be reproduced.

[0058]

The transmissivity of the color filter Cw is determined by equation (1). The brightness of the first gray level represented using only the color filter Cw is one eighth of the brightness obtained where the three color filters Cr, Cg, and Cb simultaneously provide their respective first gray levels. Therefore, where the displayed image is a black-and-white image, the upper-order 7 bits of the image data quantized with 10 bits are displayed using the color filters Cr, Cg, and Cb. The lower-order 3 bits are displayed using the color filter Cw. Consequently, 1024 gray levels can be reproduced.

[0059]

This relation is described by referring to Fig. 3. (a) shows an input signal applied to the signal converter portion 6. (b) shows the brightness of an image reproduced by the color filters Cr, Cg, and Cb. (c) shows the brightness of an image reproduced by the color filter Cw. (d) shows the brightness of the resultant of the images shown in (b) and (c) combined by the human visual characteristics. It can be observed from these figures that the number of gray levels shown in (d) is the same as the number of gray levels shown in (a).

[0060]

Where the displayed image is not a black-and-white image

but a color image, the brightness components of the color image data quantized with 10 bits can reproduce 1024 gray levels using the color filters Cr, Cg, Cb, and Cw. However, with respect to color components, only 128 gray levels can be reproduced using the color filters Cr, Cg, and Cb. Furthermore, the chroma deteriorates slightly, because white and black components are mixed by the color filter Cw.

[0061]

However, the visual characteristics of the human eye have such a feature that the eye can discriminate a less number of color gray levels than brightness gray levels. Consequently, this will not present great problems.

Only one color filter Cw is added compared with the first conventional example and so the decrease in the brightness is only about 3%. As a result, the decrease in the brightness presents almost no problems.

[0062]

The color filter Cw is only required to exhibit almost flat spectral transmission characteristics in the visible range. This filter is not limited to a filter that transmits pure white light. For example, the spectral characteristics are allowed to be shifted slightly toward red or blue.

[0063]

Embodiment 2

In Embodiment 1, Cw is used for gray levels ranging from

the first to the 1024th gray level. It is not necessary to use the color filter Cw for all the gray levels. The filter may be employed only for dark image portions. An example of operation in this case is next described by referring to Fig. 4. (a) is a diagram showing an image signal applied to the signal converter portion 6. (b) is a diagram showing the brightness of an image reproduced by the color filters Cr, Cg, and Cb, and is the same as in Embodiment 1. (c) shows the brightness of an image reproduced by the color filter Cw. This filter Cw is used for only the 15th gray level and below. The filter Cw is kept OFF in response to the 16th gray level and above. The resultant brightness of the color filters Cr, Cg, Cb, and Cw is shown in (d).

[0064]

The human eye's capability to discriminate bright portions is lower than the capability to discriminate dark portions. Therefore, where the color filter Cw is used only for dark portions to resolve gray levels, the same advantages can be obtained as Embodiment 1. Furthermore, the 16th and higher gray levels can be displayed in the same way as the prior art display device. The decrease in the chroma due to mixing of white and black components by the color filter Cw can be suppressed to a minimum.

[0065]

Embodiment 3

In Embodiments 1 and 2, 10 bits of image data are separated into the upper-order 7 bits and the lower-order 3 bits and displayed. The present invention is not limited to the bit numbers used herein. For example, $(n + m)$-bit image data (where n and m are any arbitrary real numbers equal to or greater than 0) may be divided into the upper-order n bits and the lower-order m bits and displayed.

[0066]

Embodiment 4

In Embodiments 1-3, Equation (2) is used as a formula for calculating brightness data Y. The invention is not restricted to this calculational formula. Rather, appropriate coefficients may be used according to the spectral characteristics of the color filters Cr, Cg, Cb, and Cw. Furthermore, coefficients may be varied to reduce the size of the hardware. Where signals are transmitted in Y chromatic form as in normal TV, only the Y signal of the sent Y chromatic signal may be used.

[0067]

Embodiment 5

In Embodiments 1-4, a color filter exhibiting flat spectral characteristics in the visible range is used as the color filter Cw. The invention is not limited to this. Rather, the filter may have any desired characteristics as long as it transmits white light within a realizable range. For instance,

the spectral characteristics may have some peaks and valleys, not flat. Filters having these characteristics may have advantages similar to those yielded by the aforementioned ones.

[0068]

[Effects of the Invention]

As described thus far, a display device in accordance with this invention has a light source and four or more kinds of color filters including a color filter Cw showing almost flat transmission spectral characteristics in the visible range, the display device being designed to display an image by passing light emitted from the light source through the color filters. The display device is characterized in that information corresponding lower-order m bits of a color image signal quantized with $(n + m)$ bits is displayed only with the light passed through said color filter Cw, and in that information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw. With respect to gray levels that cannot be displayed in the past due to the limitation on the minimum switching time in which a light valve is turned on and off, only brightness information to which human visual sensation is relatively sensitive can be reproduced by the color filter Cw. The gray scale can be reproduced smoothly. In addition, a decrease in the brightness can be suppressed.

[0069]

The invention also provides a display device having a light

source and four or more kinds of color filters including a color filter Cw that transmits white light, the display device being designed to display an image by passing light emitted from said light source through the color filters. The display device is characterized in that information corresponding lower-order m bits of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed through said color filter Cw, and in that information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw. With respect to gray levels that cannot be displayed in the past due to the limitation on the minimum switching time in which a light valve is turned on and off, only brightness information to which human visual sensation is relatively sensitive can be reproduced by the color filter Cw. The gray scale can be reproduced smoothly. In addition, a decrease in the brightness can be suppressed.

[0070]

In another feature of the invention, a display is provided using light transmitted through the color filter Cw only when a signal corresponding to brightness information of said color image signal is less than a given gray level. Therefore, only dark portions to which human visual sensation is relatively sensitive are reproduced by an increased number of gray levels. Bright portions can be reproduced in the same way as in the past.

A decrease in the chrominance due to mixing of brightness by the color filter Cw can be reduced to a minimum. Consequently, a natural image can be obtained.

[Brief Description of the Drawings]

Fig. 1 is a block diagram showing one example of the structure of a display device in accordance with Embodiment 1 of this invention;

Fig. 2 is a block diagram of a signal converter portion of the display device in accordance with Embodiment 1 of this invention;

Fig. 3 is a diagram illustrating a method of reproducing gray scales used in the display device in accordance with Embodiment 1 of this invention;

Fig. 4 is a diagram illustrating a method of reproducing gray scales used in the display device in accordance with Embodiment 2 of this invention;

Fig. 5 is a block diagram showing one example of the structure of a first conventional example of display device; and

Fig. 6 is a block diagram showing one example of the structure of a second conventional example of display device.

[Legend]

2, 102, 202: color wheels; 5, 105, 205: driver portions;

6: signal converter portion; 7, 8, 9: input terminals;

10: brightness signal-calculating portion;

11, 12, 13: delay-compensating portions;

14, 15, 16, 17: output terminals; 101: light source;

103: light valve; 104: screen

[Name of Document]: Abstract

[Summary]

[Object]

A display device that can eliminate a shortage of the number of gray levels due to a limitation on the minimum switching speed of a light valve and suffers from almost no brightness decrease is obtained.

[Solving Means]

A color filter Cw having nearly flat transmittance characteristics is added to a color wheel 2, other than the three primary colors. Brightness information carried by a color image signal is quantized with $(n + m)$ bits. Of this brightness information, information corresponding lower-order m bits is displayed by light passed through the color filter Cw. Information corresponding to higher-order n bits is displayed by light passed through color filters other than the color filter Cw. Consequently, only brightness information to which the human visual sensation is sensitive in terms of gray levels is reproduced by the color filter Cw having a low transmissivity.

[Selected Figure]: Figure 1